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A. Analysis of Stratospheric Ozone, Temperature, and Minor Constituent Data

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C. Research Objectives

The objective of this research is to use available satellite measurements of temperature and constituent concentrations to test the conceptual picture of stratospheric chemistry and transport. This was originally broken down into two sub-goals: first, to use the constituent data to search for critical tests of our understanding of stratospheric chemistry and second, to examine constituent transport processes emphasizing interactions with chemistry on various time scales. A third important goal which has evolved is to use the available SBUV and TOMS data from Nimbus 7 to describe the morphology of recent changes in Antarctic and global ozone with emphasis on searching for constraints to theories. The major effort now being pursued relative to the two original goals is our effort as a theoretical team for the Arctic Airborne Stratospheric Expedition (AASE).

D. Progress and Results

Our effort for the AAOE is based on the 3D transport and chemistry model at Goddard. Our goal is to use this model to place the results from the mission data in a regional and global context. Specifically, we set out to make model runs starting in late December and running through March of 1989, both with and without heterogeneous chemistry. The transport is to be carried out using dynamical fields from a 4D data assimilation model being developed under separate funding from this task. We have successfully carried out a series of single constituent transport experiments. One of the things demonstrated by these runs was the difficulty in obtaining observed low N2O abundances in the vortex without simultaneously obtaining very high ozone values. Because the runs start in late December, this difficulty arises in the attempt to define consistent initial conditions for the 3D model. To accomplish a consistent set of initial conditions we are using the 2D photochemistry-transport model of Jackman and Douglass and mapping in potential temperature, potential vorticity space as developed by Schoeberl and coworkers.

One of the problems in attempting to evaluate the impact of heterogeneous chemistry in three dimensions is that it will not be possible to simply insert all of the relevant reactions. Therefore we undertook a study of how to represent the effects of heterogeneous chemistry in a simplified form. We developed a "ring" model which was one dimensional with longitude as the variable. This model used a specified latitude, altitude and time of year and allowed for advection around the longitude with a polar stratospheric cloud existing over part of the domain. We found that the time scale for heterogeneous processing was rapid, of order 2-3 days. The time scale for recovery was significantly longer. This implies that processing of air trapped in a vortex can be accomplished with minimal cloud occurrences.

Work on TOMS data analysis continued with the observation of the behavior of the Antarctic ozone hole for 1987 and 1988. The 1987 ozone hole was the strongest on record, but 1988 showed a significant recovery. Because of the strong recovery in 1988 of the ozone in the circumpolar maximum region, the declines in ozone in southern midlatitudes do not appear quite as significant as we previously believed. Analyses of global ozone column appear to indicate 3-4% change. North polar changes are generally small, but northern midlatitude winter changes are of the order of 5%

E. Journal Publications in 1988 and 1989

Douglass, A. R. and R. S. Stolarski, "Impact of heterogeneous reactions on stratospheric chemistry of the Arctic", Geophys. Res. Lett. 16, 131-134, 1989.

Jackman, C. H. and P. E. Meade, "Effect of solar proton events in 1978 and 1979 on odd nitrogen abundances in the middle atmosphere", J. Geophys. Res. 93, 7084-7090, 1988.

Krueger, A. J., M. R. Schoeberl, and R. S. Stolarski, "The 1987 Antarctic ozone hole: a new record low", Geophys. Res. Lett. 15, 1365-1368, 1988.

Krueger, A. J., R. S. Stolarski, and M. R. Schoeberl, "Formation of the 1988 ozone hole", Geophys. Res. Lett. 16, 381-384, 1989.

Schoeberl, M. R., R. S. Stolarski, and A. J. Krueger, "The 1988 Antarctic ozone depletion: comparison with previous year depletions", Geophys Res. Lett. 16, 377-380, 1989.

Schoeberl, M. R. and R. S. Stolarski, "Reply to Elliott and Rowland", Geophys. Res. Lett. 15, 198-199, 1988.

Stolarski, R. S. "Changes in ozone over the Antarctic", in 'The Changing Atmosphere', ed. by F. S. Rowland and I. S. A. Isaksen, John Wiley and Sons, pp 105-119, 1988.

A Research Summary to
National Aeronautics and Space Administration

Title of Research Task: A Statistical Analysis of Total and Profile Ozone Data for Trend Detection

Principal Investigators: G. C. Reinsel, University of Wisconsin, Madison, and
G. C. Tiao, University of Chicago

Abstract of Research and Objectives

The principal purpose of this research is to perform statistical analyses of worldwide atmospheric total and profile ozone data over the period 1960 to 1987, for the detection of trend. Our research efforts have been concentrated primarily in the following areas: (a) time series analysis of ground-based Dobson total ozone data for trends and solar cycle effects; (b) analysis of total ozone data from the Nimbus-7 SBUV satellite experiment; (c) analysis of revised Dobson total ozone data to investigate ozone trends over different seasons; (d) analysis of the effects of stratospheric aerosols on recent ground-based Umkehr ozone profile measurements and trend analysis of the aerosol-corrected Umkehr data; (e) trend detection capability studies based on variations in the temporal sampling rate and data length of Dobson total ozone and other data.

Summary of Progress and Results

(a) Time Series Trend Analysis of Published Dobson Total Column Ozone Data

Time series regression models which include the 10.7 cm solar flux series as an explanatory variable were employed to obtain trend estimates of total ozone from a network of 37 Dobson ground stations using published data through 1987. Based on the individual station trend estimates, the resulting overall trend estimate for total ozone change over the period 1970–1987, with associated 95% confidence limits, is (–0.42 ± 0.58)% per decade. The trends display a rather strong regional variation, with trends in North American stations generally much more negative and trends in India and Japan much less negative. An overall estimate of the effect of 10.7 solar flux on total ozone was obtained as (0.99 ± 0.23)% ozone change per 100 units of 10.7 solar flux change, corresponding to about a 1.6 percent change in total ozone from solar cycle minimum to maximum.

(b) Trend Analysis of SBUV Satellite Total Ozone Data

Total ozone data from the Nimbus-7 SBUV satellite experiment were analyzed for the eight year period November 1978 to December 1986. Regression-time series models which include a linear trend term and a 10.7 cm solar flux term were estimated for both monthly average latitudinal zonal averages and a global series. A comparison between SBUV monthly average total ozone data near Dobson ground station locations and the corresponding Dobson station total ozone data for a network of 35 Dobson stations showed an average negative linear drift in SBUV data relative to Dobson data of about –0.4% per year. When the linear trend estimate for the global SBUV series is "corrected" for this negative drift, the 95% confidence interval estimate of the linear trend component in the global SBUV series over this eight year period is (–0.28 ± 0.22)% per year. The global estimate of the total ozone-solar flux relation is (1.05 ± 0.58)% per 100 solar flux units, which represents a change in ozone over this 8 year period of about (–1.71 ± 0.95)% due to solar flux.

(c) Seasonal Trend Analysis of Revised Dobson Total Ozone Data

A trend analysis of Dobson total ozone data that have been critically revised by Dr. Rumen Bojkov has been performed for 27 North Hemisphere stations between 26° N and 64° N latitude using data through 1986. The trend model considered allows for a different trend for each month of the year to examine the seasonal nature of ozone trend behavior. The trend results indicate significantly more negative trends during the winter months (December-March) than during the summer months (May-August) over the period 1970–1986, with the trends in winter becoming more negative with increasing latitude. The trends in the winter are estimated to be of the order of –1.2%, –2.1%, and –3.0% per decade, respectively, for latitudes 35° N, 45° N, and 55° N, while trends during the summer are of the order of –0.6% per decade with no distinct pattern as a function of latitude. The year-round trend over all latitudes is estimated to be about –0.84 ± 0.82% per decade. Trends based on revised data are on average more negative than trends from published Dobson data for European stations, by about –1.0% per decade, with only small average differences for North America and Japan.

(d) Analysis of Recent Umkehr Data for Trends and the Effects of Aerosols

Trend analysis of stratospheric Umkehr profile ozone data from 10 stations over the period 1977–1987 has been considered using two different correction methods to adjust the Umkehr measurements for errors caused by volcanic aerosols. Linear trend models which include the $F_{10.7}$ solar flux term were estimated for each station using both aerosol error correction methods. The trend and solar flux effect estimates are generally similar for both methods. The results indicate a significant overall negative trend, exclusive of trend variations associated with solar flux variations, of the order of –0.5% per year in Umkehr layers 7–9, and a significant positive solar cycle association in all layers 4–9. A comparison between SBUV monthly average profile ozone data near the 10 Umkehr stations and the corresponding Umkehr data corrected for aerosol errors shows a substantial overall negative linear drift in SBUV data relative to corrected Umkehr data in layers 7–9, with estimated values of the drift of the order of –1.0% per year for layers 8 and 9.

(e) Trend Detection Capability Studies

An investigation has been made, based on methodological considerations together with empirical evidence from ozone data, to examine the effects of (i) autocorrelations in the monthly average data and the length of the data records, and (ii) autocorrelations in the daily data and variations in the temporal sampling rate used to form monthly averages, on the precision of trend estimates of stratospheric variables of interest. For factor (i), the impact of the accuracy of the measurements and of the degree of month-to-month autocorrelation in the data on the required data length for trend detection has been determined. For factor (ii), it is shown that when daily measurements are moderately positively autocorrelated, the precision of a trend estimate is little affected whether it is based on monthly averages using all daily values or using only values every other day (or even every fourth day).

Journal Publications

Bojkov, R., L. Bishop, W. J. Hill, G. C. Reinsel, and G. C. Tiao (1989). A statistical analysis of revised total ozone data over the northern hemisphere, submitted to *J. Geophys. Res.*.

Reinsel, G. C., G. C. Tiao, S. K. Ahn, M. Pugh, S. Basu, J. J. DeLuisi, C. L. Mateer, A. J. Miller, P. S. Connell, and D. J. Wuebbles (1988). An analysis of the 7-year record of SBUV satellite ozone data: Global profile features and trends in total ozone, *J. Geophys. Res.*, 93, 1689–1703.

Reinsel, G. C., G. C. Tiao, J. J. DeLuisi, S. Basu, and K. Carriere (1989). Trend analysis of aerosol-corrected Umkehr ozone profile data through 1987, to appear in *J. Geophys. Res.*, 94.

Tiao, G. C., G. C. Reinsel, D. Xu, J. H. Pedrick, X. Zhu, A. J. Miller, J. J. DeLuisi, C. L. Mateer, and D. J. Wuebbles (1988). Effects of autocorrelations and temporal sampling schemes on estimates of trend and spatial correlation, submitted to *J. Geophys. Res.*.

A. Title: Study of Middle Atmospheric Transports Using Data and Models

B. Investigators and Institutions: John C. Gille, Byron Boville (1988), Guy Brasseur (1988), William Randel (1989) National Center for Atmospheric Research

C. Research Objectives: The objectives of the research are to understand the transports of trace species, chemistry and dynamics in the middle atmosphere by using data from satellites in conjunction with models. The focus is on the study of processes that are incorporated in models, or may serve to test models.

D. Summary of Progress: During 1988 considerable effort went into completing the work, and final writing of Chapter 2, Satellite Instrument Calibration and Stability, for the International Ozone Trends Panel Report: 1988 (Gille, 1988). In this chapter the calibrations of 8 satellite instruments and their stability in orbit were critically evaluated. The major conclusions were that the SBUV and TOMS diffuser plate had degraded in orbit by more than had been previously believed, and that consequently the decrease in ozone in the upper stratosphere was probably considerably smaller than had previously been reported to Congress. Similarly, the decrease in total ozone was probably no larger than suggested by the ground-based Dobson network. On the other hand, the SAGE I and II instruments were found to be stable, and the differences between them small enough that reliable trends over the 5 year differences between their missions could be determined.

In a related task in 1989, a section was prepared for the UNEP Scientific Assessment of Stratospheric Ozone: 1989 (Gille, 1989) This section reviewed the sources of data for present ozone trend analyses, as well as those data anticipated for future analyses. The conclusions were that there is an ongoing integrated ground-based and satellite system for the measurement of total ozone, but that measurements to detect trends in the vertical distribution will require development and improvement of ground-based and satellite systems.

Using newly reprocessed data from the Nimbus 6 PMR, an unexpectedly warm and high stratopause was seen in the Southern Hemisphere winter mesosphere, with an analogous but weaker feature in the Northern Hemisphere. Hitchman et al. (1989) showed that they are not radiatively created, as the lower latitude or summer stratopause is, but are dynamically driven. All evidence points to the deposition of gravity wave momentum as the drive for a downward circulation in the high-latitude winter mesosphere.

Smith et al. (1988) used LIMS data to investigate the eddy transport of non-conserved trace species, often referred to as chemical eddy transport, for ozone, nitric acid, and potential vorticity. An eddy diffusion tensor was calculated for these quantities, based on observed eddy statistics, and compared to transports calculated directly. The chemical eddy terms for ozone explain most of the observed eddy transport in the early winter, but less than half in later winter. The diffusion tensor approach can be implemented in 2D models (as is now occurring). The eddy statistics presented can be used to apply this treatment to any chemically reactive species.

Randel and Williamson (1989) studied the climate of the NCAR Community Climate Model CCM1 in comparison to ECMWF statistics, in particular using wave-mean flow interaction diagnostics to study interrelationships in model biases. Randel (1989a) documented the signatures of baroclinic wave life cycles in the troposphere (and CCM1) using cross correlation analyses; new observations included coherent, wavelike variations in zonal mean wind and temperature tendencies and coherent Ferrel cell vacillations. Randel (1989b) extended these analyses with a comparison to the life cycles of planetary waves which propagate vertically into the winter stratosphere. Those results may show the first observational evidence of Rossby wave critical layer interactions in the stratosphere. Randel (1989c) documented Kelvin wave-induced oscillations in middle atmospheric tracers measured by LIMS. Cross-spectral analyses with LIMS temperatures demonstrate regions of vertical transport, along with regions of apparent temperature dependant photochemistry. These findings may allow simple testing of middle atmospheric chemical models, and prompt the use of tracer data (such as SBUV) to document Kelvin wave variability.

E. Journal Publications–Published or Submitted Under NASA Order No. W-16, 215, 1988-1989

Brasseur, G., and M. H. Hitchman, 1988: Stratospheric response to trace gase perturbations: Changes in ozone and temperature distributions. *Science*, **240**, 634-637.

Gille, J. C., 1988: Satellite instrument calibration and stability, in International Ozone Trends Panel Report: 1988, WMO Report No. 18, in press.

Gille, J. C., 1989: Observational methods relevant to trend detection, Sec. 2.1 in The Scientific Assessment of Stratospheric Ozone: 1989, R. Watson and D. Albritton, eds., UNEP, in press.

Gille, J. C., 1989: Future observations of the middle atmosphere. In *Proceedings of the NATO Advanced Research Workshop on Dynamics, Transport and Photochemistry in the Middle Atmosphere of the Southern Hemisphere.* A. O'Neill, ed., Dordrect, Reidel, to appear.

Hitchman, M. H. and G. Brasseur, 1988: Rossby wave activity in a two-dimensional model: Closure for wave driving and meridional eddy diffusivity. *J. Geophys. Res.*, **93**, 9405-9417.

Hitchman, M. H., J. C. Gille, C. D. Rodgers and G. Brasseur, 1989: The separated polar winter stratopause: A gravity wave driven climatological feature. *J. Atmos. Sci.*, **46**, 410-422.

Randel, W. J., 1989a: Coherent wave-zonal mean flow interactions in the troposphere. Accepted *J. Atmos. Sci.*

Randel, W. J., 1989b: A comparison of the dynamic life cycles of tropospheric medium-scale waves and stratosphere planetary waves. In *Proceedings of the NATO Advanced Research Workshop on Dynamics, Transport and Photochemistry in the Middle Atmosphere of the Southern Hemisphere.* A. O'Neill, ed., Dordrect, Reidel, to appear.

Randel, W. J. and D. L. Williamson, 1989: A comparison of the climate simulated by the NCAR community climate model (CCM1:R15) with ECMWF analyses. Submitted to *J. Climate*, June 1989.

Randel, W. J., 1989c: Kelvin wave induced tracer oscillations in the equatorial stratosphere. Submitted to *J. Geophys. Res.*, August 1989.

Rodgers, C. D., 1989: A comparison of the Curtis-Godson and emissivity growth approximations. Submitted to *Applied Optics*.

Sassi, F., G. Visconti, J. C. Gille and L. V. Lyjak, 1989: Validation of parameterization scheme for eddy diffusion from satellite data. Submitted *J. Atmos. Sci.*

Smith, A. K., L. V. Lyjak and J. C. Gille, 1988: The eddy transport of nonconserved trace species derived from satellite data, *J. Geophys. Res.*, **93**, 11,103-11,122.

Research of Observed and Theoretical Variations of Atmospheric Ozone

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Abstract:

Nine years of Nimbus–7 SBUV ozone mixing ratio (October 1978–September 1987) have been used to analyze the long–term averages of seasonal and longitudinal variations in the lower, middle, and upper stratosphere over latitudes 65°S to 65°N. The annual variation amplitude is maximum over the subpolar regions at about 2 md, 10 mb, and 40 mb. The semi–annual variation is a maximum at about 4 mb over subpolar latitudes and at about 5 mb over the equator. The effect of the El Chichon aerosol cloud on the annual and semi–annual variation in the tropics is discussed. Analysis of the long–term averaged longitude variation indicates that wave 1 is dominant, particularly during winter, in the Northern Hemisphere.

Research Summary:

A major current problem involving upper atmosphere data analysis is the documentation of the time and space distribution of the principal variables, such as temperature, wind and composition of the stratosphere and mesosphere. During the past two years we have studied the ozone mixing ratio distribution as derived from the Nimbus–7 SBUV observations covering the 9–year period of available data (October 1978–September 1987). Our analyses dealt with the height and latitude distributions of the long–term average annual and semi–annual variations as well as the average major longitude variations. In addition, we documented the hemispheric differences, and in some cases, the year–to–year variations of these distributions. In most cases, the long–term data set was detrended to avoid time changes of the ozone values which were, at least in part, instrument produced.

The average climatological height–latitude ozone distribution confirms the overall patterns derived from earlier limited data coverage. During the winter/summer season, the Southern Hemisphere ozone mixing ratio values over the subpolar regions in the upper stratosphere are considerably higher (~15%)/lower(~5%) than those in the Northern Hemisphere. This is clearly the result of reversed temperature differences between the two hemispheres. In the subpolar middle and lower stratosphere the average ozone mixing ratio is almost always higher in the Northern Hemisphere because of the dominant transport at these levels. Year–to–year variations of the ozone distribution are largest in the subpolar upper stratosphere (1–2 mb) and in the northern subtropics (8–10 mb). The latter is certainly the result of the strong perturbation to the ozone 'observed' distribution caused by the aerosol plume involved in the El Chichon eruption in April 1982.

The effects of the El Chichon eruption on the seasonal ozone variations in the equatorial midstratosphere can be seen in Figs. 1 a,b where we have plotted the monthly mean detrended ozone mixing ratio at 10 mb as derived from the SBUV observations over the 9–year period (dashed lines). Also shown are the comptued annual (Fig. 1a) and semi–annual (Fib. 1b) variations. There is an obvious strong reported ozone decrease starting in early 1982 with a slow recovery by 1983. This perturbation extends to at least 10°S.

It has not yet been quantitatively determined as to how much of the ozone 'observed' decrease is an artifact resulting from errors in the data evaluation process associated with the volcanic explosion or is real and is related to ozone photochemical destruction associated with volcanic products.

At 10 mb the annual variation is dominant in the Southern Hemisphere tropical mid-stratosphere. At these latitudes the comparably small semi-annual ozone oscillation arises chiefly from the asymmetry of the annual variation—i.e., faster net ozone decrease than buildup. The amplitude of the annual variation decreases from south to north with a maximum at 20°N. At lower pressures, the amplitude of the semi-annual oscillation is much more symmetric about the equator. It is likely that in the upper layers, the semi-annual variation is, at least in part, a response to the semi-annual solar irradiance maximum in the tropics. At lower elevations (~20 mb) there is a semi-annual ozone maximum likely related to large scale tropospheric convection and subsequent temperature variation both of which are associated with the N-S migration of the thermal equator principally over the Northern Hemisphere tropics.

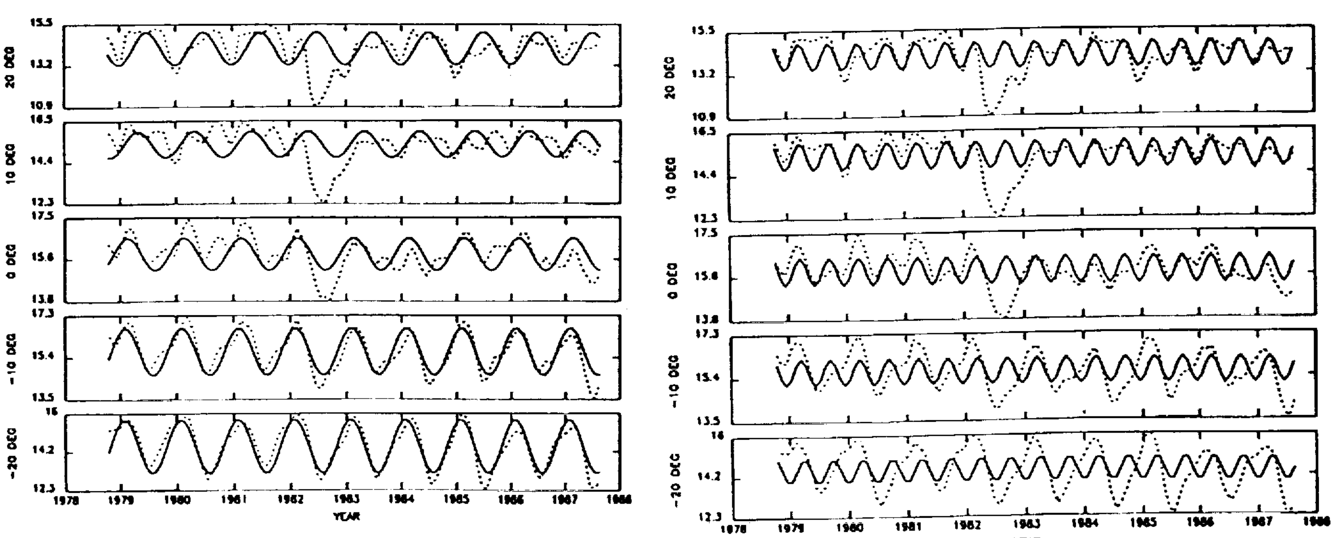
Analysis of the 9-year average longitude variations showed that at all levels the relative amplitude (amplitude/mean mixing ratio) of longitude wave 1 is dominant and is, by far, larger during winter than summer. The winter amplitude maximum is also larger in the Northern than Southern Hemispehre and is farther poleward in the Northern Hemisphere wave. At maximum, the northern winter relative amplitude over subpolar regions at 30 mb is about 10 percent. There is a double maximum of wave 1 over the tropics during all seasons, one at 10 mb, the other at 40 mb with about 150° shift in phase from 10 to 40 mb (from about 20°W to 130°E).

Publications:

London, J. and L. M. Perliski, 1988: Hemispheric differences in observed stratospheric ozone, *Proceeding of the Quadrennial Ozone Symposium*, Gõttingen, FRG, August 1988.

Perliski, L. M. and J. London, 1989: Satellite observed long-term averaged seasonal and spatial ozone variations in the stratosphere, *Planetary and Space Science* (special Dobson issue).

Fig. 1. Mid-stratospheric 10mb Ozone Mixing Ratio Variations (μmb/mb) at equatorial and subtropical latitudes (Oct 79 – Sep 87)



a) Observed (dotted)
Annual variation (solid)

b) Observed (dotted)
Semi-annual variation (solid)